AN INTERNATIONAL SOUTHERN TELESCOPE.

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(Read April 18, 1906.)

It is difficult to find a department in the arts or sciences which was not studied by that eminent and practical man, Benjamin Franklin. As his interests were mainly in the practical side of life, it is surprising that one of the least practical subjects, the study of the appearance of the heavenly bodies, should have attracted him. Yet we find that he was probably the first to bring a reflecting telescope to this country. It illustrates the widespread and keen desire of man to probe more and more deeply the sidereal universe. It is also remarkable that the reflector, after falling into disuse for many years, should now appear to be the form of telescope best adapted to this end. The object of the present paper is to propose a practical plan by which a telescope of the largest size should be so constructed and used as to lead to results of the greatest astronomical value.

So careful a study has been made of astronomy, during the last half century, that it is not easy to secure a real advance. We must learn from the success attained in industrial enterprises, and spare no pains to secure the best possible conditions in every respect, however trivial. The best location, the best form, the cost, the method of administration, and the discussion of the results will be considered in turn. It is in the last of these that the greatest advance may be expected. An attempt will be made to show how these results can be discussed, not by an individual or single institution, but by the astronomers of the world, and how numerous departments of astronomy may thus be advanced to a higher plane.

Location.

If we take a map of the world and mark upon it the principal observatories, we shall find that nearly all of them are in locations especially unsuited to good astronomical work. Almost all are near large cities, capitals of countries, or great universities. These are centers of civilization, since the climate is temperate and frequent rains promote agriculture, inland navigation, and the support of large populations. The very conditions that have rendered man's progress successful are those most unfavorable to good astronomical work. Besides these, smoke, electric lights, and jars, all fatal to the most careful study of the stars, accompany the growth of large cities. If we divide the earth into cloudy and clear halves, nine tenths of the observatories will lie in the cloudy regions.

There are three extensive clear regions upon the earth. The first and largest includes nearly all of the interior of northern Africa. There is no large observatory in that region. The second is in South Africa. The only large observatory there is in Capetown, an exceptional cloudy part of that region. The third region is the interior of Australia. The principal observatories are on the coast, at Melbourne and Sydney.

If we arrange observatories according to latitude, we find that six sevenths of them are between latitudes $+ 35°$ and $+ 60°$, or the latitudes of Spain and Scotland. A large part of the southern sky, containing many of the most interesting objects, can never be seen from the observatories of the United States or Europe. If we are to erect the greatest telescope in the world it will have a much wider field of usefulness if placed in the southern hemisphere, where comparatively neglected objects can be studied.

A location should be selected at a considerable elevation, to avoid the dust and haze of the lower atmosphere. These form the greatest obstacles to the use of a large telescope, and their effect is thus reduced to a minimum. In this respect no place is comparable with South America, where one railway attains an elevation of 17,000 feet.

Two locations suggest themselves, the west coast of South America and South Africa. The Harvard College Observatory after careful study, selected a point near Arequipa, Peru. For the last seventeen years it has maintained a station there, at an elevation of 8,000 feet. It is doubtful whether a better location can be found. although it is open to two objections. It is so near the equator that objects near the south pole are always low, and clouds are much more frequent during the summer, from November to March, than during the remainder of the year. If we go further south, the pole is higher, but the weather is more cloudy. Sir David Gill, Director of the Cape Observatory, recommends Blomfontein. It is one of the most promising locations. It is thirty degrees south of the equator, and the pole is accordingly at that height.

Form of Instrument.

In the time of Franklin, mainly through the triumphs of Sir William Herschel, the reflector was considered the best form of telescope. This form has been frequently used ever since in England, but until recently, it was seldom employed on the continent or in this country. Dr. Henry Draper, nearly half a century ago. recognizing the advantages of the reflector, constructed and used with success one of the largest yet made in this country. One firm. Alvan Clark & Sons, revolutionized public opinion regarding the best form of telescope. The desire to possess the largest telescope in the world has been a common one. There is perhaps no form of memorial which has been more widely known and admired. Five times the Clarks filled an order for the largest telescope in the world. and, in each case except the first, the previous record was their own. They accomplished this by making successively for the Mississippi. Washington, Pulkowa, Lick, and Yerkes Observatories telescopes of 18, 26, 30, 36, and 40 inches aperture. In each case the telescope was a complete success. They proved one of their principles, that whenever they could see an error they could correct it. The limit of size of telescopes of this form seems, however, to be nearly reached. The cost is very great, and the engineering difficulties become serious in the largest instruments.

The genius of one man, the late James E. Keeler, Director of the Lick Observatory, again revolutionized the views of astronomers regarding the advantages of the reflector over the refractor. Having secured a three-foot reflector which previously had done but little work, he obtained with it photographs of extraordinary perfection. Similar results have since been obtained with the two-foot reflector of the Yerkes Observatory. It has thus been shown that, in certain departments of astronomy, especially in photographing faint stars and nebulæ, results could be obtained far beyond those which had been secured with any form of refractor. One great advantage of the reflec' r is its low price. The cost of a mirror is about one tenth of that of a lens of the same size. The great defect of large refractors, the color of the images, due to chromatic aberration, is not present in reflectors. The loss of light by absorption increases rapidly with the size of the refractor, and not at all with a reflector. The difference in focus of rays of different colors is so great with a large refractor that the small dispersion needed for photographing the spectra of faint stars cannot be used. No such difference exists with a reflector. On the other hand, the reflector is much more sensitive to changes of temperature or flexure, and the silver surface becomes tarnished and must be renewed at intervals. Nevertheless, in a very large instrument the advantages of a reflector far outweigh those of a refractor.

It is therefore proposed that the telescope shall be a reflector having an aperture of about seven feet, and a focal length of forty-four feet, thus giving images on a scale of 15″ to the millimeter.

Let us imagine the instrument completed, and describe its probable construction. The polar axis is enclosed in an iron cylinder, resembling a boiler, and resting in water according to the method adopted by Mr. Common in the construction of the sixty-inch reflector now at Cambridge. There will be no difficulty from freezing, as the instrument will doubtless eventually be erected in a location having a warm climate. It would be better, if possible, to counterpoise the telescope, taking a large part of the weight off the bearings of the polar axis by a series of ball bearings, if motion of sufficient uniformity can thus be secured. Electric motors furnish abundant power for the motions in right ascension and declination, and a motor controlled by a clock is used for following. This method was employed with entire success in the Harvard telescope, 135 feet long, sent to Jamaica in 1901, and in other telescopes. (See *Astrophysical Journal,* XV, 202.)

The photographic plate is placed at the principal focus of the telescope. For visual work, this is replaced by an inclined mirror which reflects the beam of light to the side of the tube. It then falls upon an astronomical objective of five or six inches aperture, and after undergoing a second reflection, is brought to a focus in the prolongation of the declination axis of the telescope. It is here enlarged by an eyepiece in the usual way. All objects on the meridian, or at the same hour angle, are thus viewed by the observer without changing his position. He and his recorder are enclosed in a small observing room which protects them from the wind, and which may be warmed if desired. When the object is near the meridian, the observer is looking horizontally, and east or west. As the object moves, the inclination of the line of sight gradually changes, about fifteen degrees an hour. It is probable that the instrument will be used principally for photographic work, and the same method will be employed for following. The possibility of observing a distant object in this way has been established at Harvard, since 1870, with the two eight-inch collimating telescopes of the meridian circle. The images compared in this case are nearly forty feet apart. An important use of the instrument will be in photographing the spectra of faint stars. These will be taken in two ways. A concave and convex lens are inserted near the focal plane of the telescope, and between this plane and the principal mirror. Their positions are such that between them the cone of rays of each star is parallel. A prism is inserted as described more fully in Harvard Circular 108. For measuring the approach and recession of faint stars, as described in Harvard Circular 110, a similar device is employed. As a large dispersion is required, the prism has such an angle that the cone of rays is inclined, and comes to a focus outside the tube of the telescope. The photographic plate, therefore, does not intercept any part of the incident rays. The reversed spectrum is formed by turning the lenses, prism, and plate 180°.

Cost.

To establish an observatory of the first class is a costly operation. The expenditure for plant, land, buildings, and instruments should be two or three hundred thousand dollars. The annual income of the Greenwich, Paris, Pulkowa, and Harvard observatories is about fifty thousand dollars, in each case. To secure this permanently at four per cent. the sum of $1,250,000 would be required. Accordingly, the total cost would be $1,500,000. To duplicate the resources of the U. S. Naval Observatory would involve an expenditure of at least double this sum, or $3,000,000. A sixth part of the last named sum, or $500,000 would suffice to carry out the plan proposed in this paper. Figures can be given with a good deal of confidence since, at Harvard, we have had experience of a nearly similar character. A reflecting telescope of two feet aperture and its mounting have recently been constructed at a cost of less than $4,000. For a larger telescope we may assume that the cost of drawings and plans will be proportional to the first power, the cost of the machine- and hand-work to the square, and of the material, to the cube of the dimensions. At this rate, telescopes of six, seven, and eight feet aperture would cost $42,900, $63,000, and $87,400, respectively. The five-foot telescope at Harvard cost us much less than this rule would imply, but the conditions under which it was acquired were exceptional. Assuming the cost to be proportional to the cube of the dimensions, we have the cost in the three cases $108,000, $171,500, and $256,000. The actual cost would probably lie between these rather wide limits, but it is believed that a telescope of seven-feet aperture and mounting could be constructed for $150,000.

The current expenses can be closely estimated since, for seventeen years, the Harvard Observatory has conducted an auxiliary observing station in South America. Ten thousand dollars a year would be needed to carry on the proposed station satisfactorily. To produce this sum, allowing four per cent. interest, $250,000 would be required. With the income, three or four assistants could be maintained, who would keep the telescope at work throughout every clear night, and perhaps some smaller instruments. A certain amount of the income would be available for publication and for subsidies paid to astronomers here or in other countries, for assistants who would aid them in measuring and discussing the photographs. Before the large telescope is completed the interest on the principal would defray the expenses of the preliminary work of testing locations with smaller instruments, erecting houses for the observers and similar work. If the fund had an independent foundation, an additional $100,000 would be required for an executive for the management of the fund, etc. This would be saved if the superintendence would be undertaken without charge by the Harvard or some other existing observatory. The entire amount required would, therefore, be $400,000 or $500,000, which at most would only be a third of that required for an observatory of the first class and of the usual form.

Method of Administration.

The administration and management of the fund would, of course, rest with the donor. If it were left to me, I should at once write to the principal makers of glass for estimates of the cost and time required to furnish a disk of glass seven feet in diameter and one foot thick. An expedition to South Africa would next be planned, equipped with the two-foot reflector of the Harvard Observatory. This instrument would be mounted in the best available location, and regular work undertaken which would test the steadiness and other qualities of the atmosphere. Tests would also be made of various adjacent localities, with refracting telescopes of four, five or six inches aperture. Meanwhile, correspondence would be opened with all those astronomers likely to give useful advice, and a committee would be formed of such astronomers as would attend a meeting at an early date. Thus, no time would be lost. The form of mounting would be the principal subject to be discussed at the first meeting, and the work of construction would be begun as soon as this point was settled. The results of the first expedition would probably serve to determine whether a better location could be found in South Africa than that we now occupy in Peru.

Discussion of Results.

Not only from its size, but from its exceptional location, this telescope ought to give better results than those previously obtained in almost every department of astronomical science. Its principal use will be in photography, determining the positions, brightness, and spectra of faint stars, especially novæ and variables, in depicting clusters and nebulæ, in studying the distribution of faint stars, in discovering and following faint satellites and asteroids, in measuring parallaxes and proper motions, and, in general, in studying all the properties of stars beyond the reach of smaller instruments.

In visual work, very high powers could be employed, without the difficulties usually encountered from diffraction when a very small emergent pencil is used. Owing, also, to the great light gathering power, it is probable that visual observations of the surfaces of the outer planets, especially Uranus and Neptune, could be made to great advantage.

Evidently the material accumulated photographically would greatly exceed what could be properly discussed by a single individual or institution. Especial pains should be taken to place this material in the hands of any astronomers qualified to use it. The entire collection of photographs should eventually be kept together, where it could be consulted, but copies or enlargements of any portion or of the whole should be furnished at cost to any one desiring them. Qualified astronomers, ready to discuss any portion of the work, should be offered the use of the original negatives, given copies, and in every way aided in discussing and preparing the results for publication. It is desirable that they should be published in a separate series of quarto volumes. The fundamental principle should be that the results are for the world and not for a single individual, and every concession should be made to secure the widest use of the material collected. The telescope should be kept at work throughout every clear night. A scheme of work should be prepared every year by the aid of an international committee of astronomers, which should provide for a proper division of the time of the telescope, secure assistance and advice in discussing the results, and, in general, aid in obtaining the best administration. For instance, such a committee might spend several days together in New York, travelling and hotel expenses being paid, and care being taken that at least one European astronomer should be present each year. A German delegate might report that in his country a particular astronomer desired to study the distribution and brightness of the stars in globular clusters. A hundred hours might be assigned to this work and five photographs of each of ten clusters would be taken with exposures of two hours each. Contact prints would be made of these photographs and the originals sent to the German astronomer, who might be furnished with means for paying the salary of an assistant who would make the measures under his direction if the work was considered of sufficient importance. When the research was completed, the original negatives would be returned and added to the rest of the collection. The results would be printed in the series of annals, giving the author as many copies as he could usefully distribute. On special occasions, as during an opposition of Mars, a specialist might be invited to the observatory and the telescope placed, for the time, at his disposal. It would be difficult to find useful work for the telescope when the moon was full. Such researches as photometric measures of the relative brightness of the components of close double stars and studies of the moon and planets could be made at such times.

Conclusions.

To sum up the results of this paper, it may be said that the desire to have the largest telescope in the world and to carry our knowledge of the stars farther than has ever been done before, has been very widespread. It would be unwise to construct a refracting telescope much larger than those already made. A million and a half dollars would be required to duplicate one of our present observatories of the first class. A reflecting telescope of seven feet aperture, larger and more powerful than any hitherto constructed, could be made at a moderate price. It should be mounted in the best possible location as regards climate, and preferably in the southern hemisphere, to permit the study of neglected regions. Such an instrument would produce, by photography, results in quality much better than can be obtained elsewhere and in such quantity that no single institution could discuss and publish them. These photographs should be distributed throughout the world, and astronomers of all countries would thus be furnished with better material for study than they could possibly obtain themselves. They would also be offered every aid in discussing and publishing their conclusions.

The estimated cost of carrying out this plan is not more than half a million dollars, or one third of that of an observatory of the usual form as now constructed. Not only would results be obtained superior to those now secured anywhere else, but the work would be planned, not by a single astronomer, but by an international committee of astronomers, and the results would be discussed by the most distinguished specialists in each department. In this way, following the example of the great industrial enterprises of the country, the plan of work would be improved continually in every detail.

It will be difficult during the twentieth century to make as great an advance in science as was done during the life of Franklin in the eighteenth century or after his death in the nineteenth century. How could the name of Franklin be more highly honored than by initiating this undertaking at his bi-centennial? Were he living, is there any way that would be more in accordance with his wishes and aims in life than to advance a science, not only in a direction, but by a method, which would bring together, as here proposed, experts from all parts of the world in a single field of work.

It is not easy for a man who by life-long work and skill has accumulated a large fortune to expend it wisely in science and to his own satisfaction. It is hard for him to see it wasted or yielding inadequate results. Money thus given should be expended, as it has been acquired, by careful management and the use of strict business methods, in order to obtain the greatest return for every disbursement.

The name of a donor could in no way be better immortalized than by associating it with such a real advance in the greatest problem to the solution of which the mind of man has aspired,—the study of the sidereal universe.